

Excitation Function of the Longitudinal Expansion in Central Nuclear Collisions

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Abstract. Longitudinal hadron spectra from Proton-Proton (pp) and nucleus-nucleus (AA) collisions from $E_{lab} = 2$ AGeV to $\sqrt{s} = 200$ AGeV are investigated. The widths of the rapidity spectra for various particle species increases monotonously with energy. The present calculation indicates no sign of a step like behaviour as expected from the Kaon transverse mass systematics. For Pions, the transport simulation is consistent with a Landau type scaling of the rapidity widths, both in central AA reactions and in pp collisions. However, other hadron species do not follow the Landau scaling. The present model predicts a decreasing rapidity width with particle mass for newly produced particles, not supporting a Landau type flow interpretation.

Based on recent lattice QCD (lQCD) calculations it has been speculated that partonic degrees of freedom might already lead to visible effects at ~ 5 A·GeV [1]. Especially the hardening of the measured transverse mass (m_t) spectra in central Au+Au collisions relative to pp interactions [2, 3] around AGS energies obtained great interest and was studied in detail [4]. This increase of the inverse slope parameter T is commonly attributed to strong collective flow, which is absent in the respective pp or pA collisions. It has also been proposed [5] to interpret the high and approximately constant K^\pm slopes above ~ 30 AGeV – the ‘step’ – as an indication of the phase transition.

This interpretation seems supported by microscopic transport simulations

- indicating the increasing importance of sub-hadronic degrees of freedom above AGS energies [6] and
- from the comparison of the thermodynamic parameters T and μ_B extracted from the transport models in the central overlap region [7] with the experimental systematics on chemical freeze-out configurations [8, 9, 10] in the T, μ_B plane.

Let us now explore whether a similar ‘step’ is also present in the excitation function of longitudinal observables. For the present study we employ the UrQMD model (v2.2) [11, 12]. It takes into account the formation and multiple rescattering of hadrons and dynamically describes the generation of pressure in the hadronic expansion phase. It involves also interactions of (di-)quarks, however gluonic degrees of freedom are not treated explicitly, but are implicitly present in strings. This simplified treatment is generally accepted to describe Proton-Proton and Proton-nucleus interactions.

It became popular to interpret relativistic heavy ion reactions with Landau’s hydrodynamical model [13, 14, 15, 16, 17, 18] (for recent applications of this model to relativistic nucleus-nucleus interactions see [19, 20, 21, 22]). Therefore we will use this simple hydrodynamical picture as a baseline for the model and data comparison. The main physics assumptions of Landau’s picture are: The collision of two Lorentz-contracted hadrons or nuclei leads to full thermalization in a volume of size $V m_p / \sqrt{s}$. This justifies the use of thermodynamics and establishes the system size and energy dependence. A simple equation of state $p = \epsilon/3$ is assumed. Chemical potentials are usually assumed to vanish. The main results derived from these assumptions are: A universal formula for the produced entropy, determined mainly by the initial Lorentz contraction and Gaussian rapidity distributions, at least for newly produced particles. The results can be summarised in the energy dependent rapidity density [17]:

$$\frac{dN}{dy} = \frac{K s^{1/4}}{\sqrt{2\pi L}} \exp\left(-\frac{y^2}{2L}\right) \quad \text{with} \quad L = \sigma_y^2 = \ln(\sqrt{s}/2m_p). \quad (1)$$

As depicted in Fig. 1 (left) the UrQMD predictions (full circles) for the rapidity widths of negatively charged Pions in Au+Au (Pb+Pb) reactions are in line with the experimental data [22] (full diamonds) and Landau’s hydrodynamical model (full line). A rather surprising observation is that the calculated rapidity widths of π^- in pp interactions (open squares) are identical to the AA results.

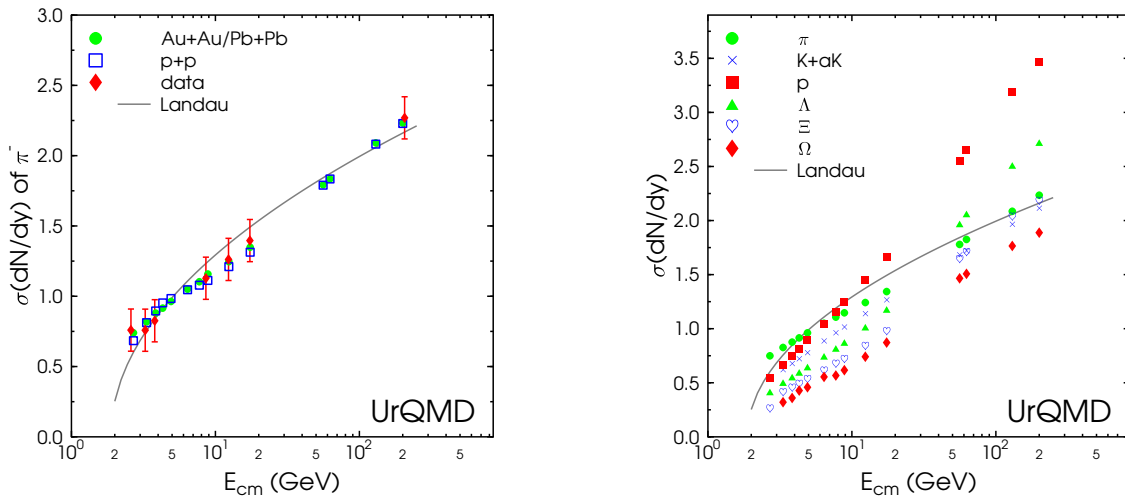


Figure 1. Left: The root mean square of the rapidity distribution of negatively charged Pions in central Au+Au/Pb+Pb and Proton+Proton reactions as a function of the center of mass energy. UrQMD calculations for Au+Au/Pb+Pb are denoted by full circles, the pp results are shown by open squares. The prediction from Landau's model is given by the line (Eq. 1). Data [22] are depicted by full diamonds. Right: The root mean square of the rapidity distribution of Pions, Kaons, Protons, Lambdas, Cascades and Omega hadrons in central Au+Au/Pb+Pb reactions as a function of center of mass energy. UrQMD calculations for Au+Au/Pb+Pb are denoted by symbols. The prediction from Landau's model is given by the line.

The rhs. of Fig. 1 shows the rapidity widths of different particle species as a function of energy. Here the calculation (for hadrons other than Pions) differs considerably from the Landau model: (I) Hadrons containing (initial) up or down quarks show a strong increase of the rapidity widths with energy (leading particle effect). (II) Hadrons without initial up or down quarks show a decreasing rapidity width with increasing mass at fixed energy.

The second feature is shown in detail in Fig. 2 for central Au+Au reactions at $\sqrt{s} = 200$ AGeV. Here the root mean square of hadrons without initial quarks is given as a function of particle mass. Beginning from Pions with rapidity width of 2.2 units up to anti-Xi baryons with a rapidity width of only 1.65 units. Within 10% deviations, this results in Bjorken-plateau of $y_{cm} \pm 0.75$.

In conclusion, we have explored the excitation functions of the rapidity widths of Pions, Kaons, Protons, Lambdas and Xis in pp and/or AA collisions. The rapidity spectra of Pions for all investigated systems and energies can be described well by Gaussians. The energy dependence of the width of the Pion rapidity distribution follows the prediction of Landau's hydrodynamical model, both in nucleus-nucleus and Proton-Proton interactions. In nucleus-nucleus reactions, the width of all other investigated hadrons deviates from the Landau picture. For newly produced hadrons, the present calculation shows a strong mass dependence of the rapidity width, allowing for a Bjorken-plateau only in a narrow window ($y_{cm} \pm 0.75$ at the highest RHIC energy) around

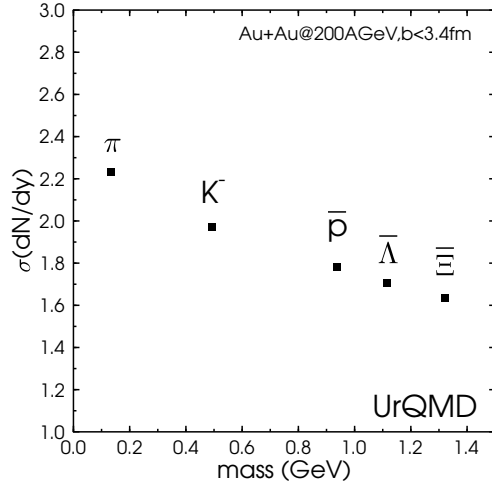


Figure 2. Root mean square of the rapidity distribution as a function of particle mass in central Au+Au reactions at $\sqrt{s} = 200$ AGeV.

midrapidity. We do not observe any irregularities (e.g. steps or peaks) in the rapidity width of all investigated hadrons.

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